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PEPAB NORM DEVELOPMENT (PEPABNRM)

FINAL REPORT

LESLIE CAROL MONTGOMERY
PATRICIA A. DEUSTER

DECEMBER 19, 1991

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Uniformed Services University of the Health Sciences
4301 Jones Bridge Road
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We developed a tool for predicting the treadmill speed at which to run subjects in order to elicit a desired percentage of their maximal aerobic capacity. We generated, tested and refined a pair of regression equations: one for submaximal aerobic exercise, the other for high-intensity anaerobic exercise. Within the limitations of using linear equations to elicit physiologic responses that are sometimes curvilinear, the equations are useful to researchers.

Measures from an Actigraph activity monitor were validated against measures of heart rate and oxygen consumption ($\dot{V}O_2$) while subjects performed a series of sedentary and physically challenging tasks. The Actigraph could be used to grossly estimate energy expenditure because of the relation of oxygen consumption to energy expenditure (5 kilocalories are expended for each liter of oxygen consumed).

We compiled a normative data base (N=119) of all subjects tested to date; results are appropriate for comparison to other healthy, physically active populations. Lastly, we developed a computerized physical activity questionnaire (PAQ) to quantify average daily energy expenditure. The PAQ quantifies work, sleep and leisure time-activities over a one-week and/or one-year period. Although dependent on the accuracy of subject recall, the PAQ has proven to be a useful tool for estimating energy expenditure in over 60 subjects.

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FOREWORD

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Patricia D. Duette — 18 Dec 1991
Principal Investigator's Signature — Date

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I. CREATION OF A NORMATIVE BASE

In the past six years, hundreds of treadmill exercise tests on military and civilian personnel were conducted in the Human Performance Laboratory (HPL) of the Uniformed Services University of the Health Sciences. All of the subjects were healthy and free of cardiovascular disease as evidenced by normal electrocardiographs during rest, maximal exercise and recovery. Since most exercise tests at universities and medical facilities utilize a bicycle ergometer rather than a motorized treadmill, it is unusual to have such a large pool of data on subjects who underwent maximal treadmill testing. In addition, most facilities are not equipped to directly measure oxygen consumption; they rely instead on predictions of oxygen consumption based on the subject's heart rate. Since bicycle tests are often submaximal rather than maximal, even the maximal heart rate is predicted rather than being directly measured. While the accuracy of submaximal bicycle ergometry in evaluating physical fitness is not being questioned here, direct measurement of oxygen consumption during a maximal exercise test is preferable for accurately quantifying the aerobic capacity (maximal oxygen uptake [$\dot{V}o_{2max}$]) of an individual.

We have pooled the data from all of the maximal exercise tolerance tests conducted in the HPL in order to profile healthy adults and provide a means of comparison to other populations. This normative data base, first described in the FY 91 second quarter report, is now completed. Every subject who underwent treadmill testing in the past six years was included (N = 119). Results are presented in Table 1, by gender. Sixty percent of the subjects were active duty military personnel (both enlisted and officers) and the remainder

were civilians. There were no statistically significant differences between military and civilian personnel except for the following: male military personnel had a significantly higher mean body mass index (BMI = weight in kilograms divided by height in meters squared) than civilians (24.5 vs. 23.2, respectively; $P < 0.05$). This difference in BMI was driven by a difference in body weight (military: 78.1 kg vs. civilian: 74.5 kg, P = 051). In Table 2, data are presented by gender and age decile: 20 - 29 years and 30 - 39 years. The only statistically significant difference between age groups was in the male's body fat percentage ($P = 0.0072$), with the younger men being leaner.

Our subject population differs from most published populations in a few respects. First, the mean age of roughly 30 years distinguishes our population from studies of collegiate or "middle-aged" individuals. Second, the average maximal oxygen consumption ($\dot{V}o_{2max}$) values of 46 and 55 $ml \cdot kg^{-1} \cdot min^{-1}$ for females and males, respectively, indicate an above average level of physical fitness. Nearly all subjects reported being at least moderately physically active, and a few were highly trained amateur athletes. Third, since most of the studies conducted in our lab use prolonged or intensive exercise as a stressor, our subjects self-selected as those who could tolerate moderately to extremely strenuous exercise. Thus, our results should be appropriate for comparison with healthy, recreational athletes and most military populations, but may not be reflective of the general--viz., sedentary--population.

II. MODIFICATION OF THE TREADMILL PROTOCOL USED TO DETERMINE MAXIMAL OXYGEN UPTAKE

Since 1987 we have been using the USARIEM treadmill protocol for maximal exercise stress testing.[2] This protocol was developed by Taylor et al.[10] and then modified by Sawka et al.[9] Treadmill speed is determined by the heart rate at the end of a 10-min warm-up walk (3.5 mph on a 10% grade): if the heart rate is over 145 beats per minute (bpm), the speed is set to 6 mph; if the heart rate is less than 145 bpm, the speed is set at 7 mph. In Figure 1, a frequency distribution is presented of 74 subjects who were tested using the USARIEM protocol at 7 mph. The mean time on treadmill, excluding the warm-up, was 11.06 minutes which is in the desired range of time for an exercise tolerance test (8-12 minutes)[1]. However, 23 of 74 subjects (31%) ran for longer than 12 minutes (range = 12.05 - 15.583 min). In tests that last considerably longer than 12 minutes, factors other than the capacity for oxygen delivery, such as muscular or joint pain, overall fatigue, or even boredom, may cause the subject to stop exercising. Thus, for certain subjects, the treadmill protocol was not strenuous enough to be completed in 12 minutes or less.

In order to appropriately challenge the more physically fit subject, in our FY 91 second quarter report we suggested adding an additional speed of 8 mph for use with certain subjects. The criterion measure for determining which speed to use (6, 7 or 8 mph) would still be the end of warm-up heart rate; however, if the heart rate was less than or equal to 115 bpm, then the treadmill speed would be set at 8 mph. The value of 115 bpm was chosen based on results from the 23 subjects who ran at 7 mph for longer than 12 minutes: they had a mean end of warm-up heart rate of only 112 bpm. With this speed

modification, we anticipated that treadmill tests would be completed within 12 minutes which we found desirable based on the findings of Wasserman et al. that the highest $\dot{V}o_{2max}$ values were obtained when the incremental portion of the protocol was completed between 6 and 12 minutes.[11]

Another important consideration was to have the subjects run at a speed that approximated their training pace; this has been shown to result in lower ratings of perceived difficulty by the subjects.[3] By increasing the treadmill speed to 8 mph in those subjects who are highly fit (as evidenced by a heart rate $\leq$ 115 bpm at the end of the warm-up), time on treadmill would be reduced, hopefully, to within a target range of test duration of 10 $\pm$ 2 minutes.[4] Since adopting this change in protocol, 5 males have been tested at 8 mph. Their mean $\dot{V}o_{2max}$ was 61 $ml \cdot kg^{-1} \cdot min^{-1}$ (range 51.6 - 71.5) and the mean time on treadmill was 9.71 minutes (range 7.88 - 12.0).

III. CORRELATIONS OF AN ACTIVITY MONITOR WITH PHYSIOLOGIC MEASURES OVER A RANGE OF ACTIVITIES

A. Introduction

A description of the study in which we examined the correlations among oxygen consumption, heart rate and Actigraph activity monitor recordings was presented at length in the FY 90 Annual Report and in brief in the FY 90 Quarterly Report for the fourth quarter. The information which follows is excerpted from a talk entitled "Exercise and the Actigraph Activity Monitor" that the associate investigator presented at the annual OMPAT meeting in August, 1991.

In 1990, we examined the correlations among activity "counts" (measures obtained from the Actigraph™ activity monitor), oxygen consumption ($\dot{V}o_2$) and

heart rate across a range of intensities of physical activity. The goals of the study were to: test the validity and reliability of the Actigraph across a range of sedentary daily activities and physical exercise activities; test the correlation of Actigraph counts with heart rate and oxygen consumption; and examine the sensitivity of the Actigraph to discriminate among a range of activities, as well as to detect a change in the intensity of any given activity.

B. Methods

The activities that the subjects performed were selected because they were similar to those chosen in two previous studies of portable activity monitors. Redmond and Hegge[7] had one subject perform a range of activities including reading, typing, walking, jogging, and vigorous calisthenics. Prior to this, Wong et al.[12] had 15 subjects wear an accelerometer on their waist and then walk, jog and run on a motorized treadmill. In the present study, subjects performed mental arithmetic, read, typed, and played a video game (2 mins per task; 1 min between tasks). Activities were randomized with the exception that mental arithmetic was always performed first since the subject needed to verbalize. The subject was then outfitted with the mouthpiece apparatus for measuring oxygen consumption following the math task and before all other tasks. The physical exercise activities were knee bends at 28 and 48 bends per minute (bpm), step climbing at 20 and 36 steps per minute (spm), and running on a motorized treadmill at four different speeds ranging from a walk to a sprint. The tasks were randomized, but the slower pace always preceded the faster pace within task. Treadmill exercise at all intensities occurred either before or after the knee bends and step climbing tasks. Task length was 2 mins with a 1 min rest in between for the knee bends and step

climbing, and 3 mins per speed for the treadmill exercise with no rest between speeds. During all sedentary and exercise activities, heart rate and oxygen consumption were continuously monitored (except for the mental arithmetic task).

C. Results

Figure 2 presents the oxygen consumption, heart rate and Actigraph values from the sedentary tasks. The Actigraph counts were significantly different between each task. However, none of the four sedentary activities' Actigraph counts were significantly correlated with heart rate or $\dot{V}o_2$ when examined separately. However, when all sedentary activities were averaged, Actigraph counts were significantly correlated with heart rate ($r = 0.348$, $P < 0.001$) and $\dot{V}o_2$ ($r = 0.464$, $P < 0.001$). Note that heart rate was highest during the mental arithmetic task (math) while Actigraph counts were lowest.

In Figure 3 a similar graph is presented for the non-treadmill physical exercise tasks and in Figure 4 for the treadmill tasks. The Actigraph discriminated the changes in intensity within all physical exercise tasks, but could not discriminate between knee bends at 48 bpm and step climbing at 20 spm (see Figure 4). Actigraph counts from these tasks showed a significant correlation with heart rate ($r = 0.599$, $P < 0.001$) and $\dot{V}o_2$ ($r = 0.628$, $P < 0.001$). When all physically challenging tasks were examined together, the strength of the correlation was increased: Actigraph counts and heart rate $r = 0.709$, $P < 0.0001$) and Actigraph counts and $\dot{V}o_2$ $r = 0.729$ ($P < 0.0001$). When Actigraph counts and heart rate together were correlated with $\dot{V}o_2$, the r value was 0.999. However, heart rate alone is correlated with $\dot{V}o_2$ ($r = 0.807$).

In order to determine the reliability of the Actigraph counts, four subjects repeated the entire test protocol. The test-retest correlation for all activities was very high ($r > 0.98$, $P < 0.0001$).

D. Discussion

Based on this study, we concluded that: the Actigraph differentiated among a broad range of physical activities; Actigraph counts were correlated with heart rate and oxygen consumption measurements during exercise; and Actigraph counts were highly repeatable. However, in some instances, such as when there was high mental arousal and low physical demand (such as the mental arithmetic task) there was an inverse relationship between heart rate and Actigraph counts. Similarly, if a task had low energy demand but was high in wrist movement (as in the video game task), Actigraph counts were inordinately high. These exceptions demonstrate the potential problems in measurement interpretation if heart rate or activity monitors are used independently of each other.

Despite its shortcomings, because of its correlation with physiologic measures, the Actigraph may be a useful tool for assessing the energy demands of specific physical tasks. The strength of the correlations of Actigraph counts with heart rate and oxygen consumption suggests that oxygen consumption could be fairly well predicted using a combination of Actigraph counts and heart rate measurements. Thus, during light to heavy physical activity, these two non-invasive measures may provide sufficient information to estimate oxygen consumption and may be a useful tool for estimating the oxygen consumed when performing a wide range of activities in the field. Furthermore, since oxygen consumption values are directly related to caloric expenditure (5 kcal expended per liter of oxygen consumed), the Actigraph and heart rate measures

could also provide a gross estimate of the energy cost of various physical activities.

IV. REFINEMENT OF THE REGRESSION EQUATION FOR PREDICTING TREADMILL SPEED FOR SUBMAXIMAL EXERCISE TESTING

To evaluate physical performance under a variety of treatment conditions, submaximal exercise tests often are administered. A submaximal test can simulate the work intensities of occupational or recreational activities and thus provide an accurate model for evaluating treatment effects. Furthermore, some metabolic and hormonal responses of interest to researchers are affected by exercise in an intensity-dependent manner. For these reasons, it is useful to have a tool whereby a workload can be selected that will elicit the desired intensity of submaximal effort. One tool would be a regression equation that would predict the treadmill speed necessary to obtain a desired level of effort. This level of effort is quantified as a percentage of the subject's maximal oxygen uptake ($\dot{V}o_{2max}$).

As previously reported, we have developed a number of regression equations which were subsequently used to predict the treadmill speeds at which to test subjects in order to elicit oxygen consumption values ranging from 30 to 90 percent of $\dot{V}o_{2max}$. The initial regression equations (one for moderate, continuous exercise and the other for high-intensity, intermittent exercise) were described in detail in our Technical Manual[5] and the 1990 Annual Report. These equations were used in a number of test protocols[4] and, as our subject data base continued to grow, the regression equations were repeatedly revised.

The next major iteration of the equations was used in the study of the Actigraph activity monitor and its validation with measures of heart rate and

oxygen consumption, as described in the 1990 Annual Report, Section III above, and elsewhere[6]. After data from the 15 subjects who participated in the Actigraph study were added to the data base, the equations were updated again. These equations were validated in the repeated treadmill testing of 18 subjects during the past year. Based on these most recent test results, the equations were revised one last time.

The current regression equations derive from a data base which consists of 61 healthy male subjects. Because of the different demands of running continuously versus intermittently, we generated two separate equations: one for continuous running and another for intermittent running. Using SAS statistical software[8], a Pearson correlation coefficients matrix was generated using all performance measures ($\dot{V}o_{2max}$ in $ml \cdot kg^{-1} \cdot min^{-1}$ and $L \cdot min^{-1}$, time on treadmill, maximal heart rate) and subject physical characteristics (age, height, weight, percent body fat, body mass index, and lean body mass). Any variables that were significantly ($P < 0.05$) correlated with each other (e.g., percent body fat and $\dot{V}o_{2max}$) were not used together in subsequent regression analyses. An R-square (R^2) analysis was used to identify the variables that were the strongest predictors of treadmill speed. Then, stepwise regression analysis was used to determine the actual variables in the regression equations; these variables were all independent of one another, as determined by the correlation matrix. The variables that had the highest predictive (R^2) values for both continuous and intermittent running were used in the equations: the subject's $\dot{V}o_{2max}$ in $ml \cdot kg^{-1} \cdot min^{-1}$, the pre-determined treadmill grade (GRADE) and the target percent of $\dot{V}o_{2max}$ (PCTMAX). The two regression equations are:

Continuous running (R^2 = 0.9894, r = 0.9947):

$$0.054148*PCTMAX - 0.280797*GRADE + 0.060198*\dot{V}o_{2max}$$

Intermittent/High Intensity Running (R^2 = 0.9922, r = 0.9961):

$$0.038335*PCTMAX - 0.107583*GRADE + 0.112977*\dot{V}o_{2max}$$

In general, all the equations we have developed predicted treadmill speeds that were within 0.4 miles per hour of each other at any given intensity. Adding additional variables to the equation such as body mass index or age did not add significantly to the accuracy of the equation. For these reasons and for simplicity, only three variables were used in the equations.

As confident as we are in the general utility of the equations, we do foresee some limitations in the application of the equations. First, it appears that the slope of the linear equations may not match the slope of physiologic responses to increasing intensities of exercise. We circumvented this limitation by generating two equations with different slopes: one for low intensity continuous exercise and the other for high intensity exercise. A curvilinear model for the regression equations may be more accurate. Second, because of the variation between subjects in their anaerobic thresholds, the transition point from using the "low" intensity equation to the "high" intensity equation is blurred. For some people, exercising at an intensity over 50-60% of their $\dot{V}o_{2max}$ requires substantial anaerobic metabolism and the exercise itself cannot be maintained for very long. For others, running at 80% of their $\dot{V}o_{2max}$ is steady-state exercise and well-tolerated. The individual's anaerobic threshold and capacity to tolerate anaerobic exercise are factors to be considered when selecting--and designing--regres-

sion equations. Our recommendation, given the current two equations, is to use the "low" intensity equation for continuous exercise up to 85% of $\dot{V}o_{2max}$. The "high" intensity equation could be used for all other exercise with this modification: for continuous running, use a 10% grade in the equation, but run the subjects at a 5% grade. For intermittent running the high intensity equation could be used without modification.

In sum, we developed and refined a useful tool for predicting the treadmill speed at which to test subjects to elicit a desired percentage of their $\dot{V}o_{2max}$. This tool consists of two regression equations: one equation for continuous exercise and another for high-intensity intermittent exercise. Although designed specifically for use with the Performance Physiology Assessment Battery[5], these equations may be of use to other researchers or clinicians.

V. DEVELOPMENT OF A COMPUTERIZED PHYSICAL ACTIVITY QUESTIONNAIRE

As reported in detail in the FY 90 Annual Report, we have developed a computerized questionnaire for quantifying an individual's physical activity patterns. The Physical Activity Questionnaire (PAQ), as described in previous reports, gathers general descriptive data on sleep and work habits and more specific data on the number of hours spent performing various leisure-time recreational and sports activities. Over 60 activities are listed, ranging in physical intensity from handiwork (e.g, knitting) to swimming competitively. Many of the activities are further subdivided by intensity (usually pace or distance). The activity's intensity code and the subject's body weight (kg) are multiplied together; the resulting value is an estimate of the number of calories expended per minute during performance of that activity. Data from

all activities are summed, by week and/or by year, and added to the descriptive data (sleep and job-related activity). The end result is a report which provides a gross estimate of the number of calories expended per day, on average, and also a breakdown of caloric expenditure by activity.

Approximately 60 subjects have completed the PAQ thus far, and most find the information useful and fairly accurate. Unfortunately, the PAQ can be tedious to complete if one partakes in many leisure time activities or if the data are for the whole year rather than for the current week. In addition, some subjects have difficulty in translating their workouts into minutes per week, as opposed to miles per week as with running. Still, the PAQ is a useful tool both for quantifying level of physical activity and for estimating daily energy expenditure.

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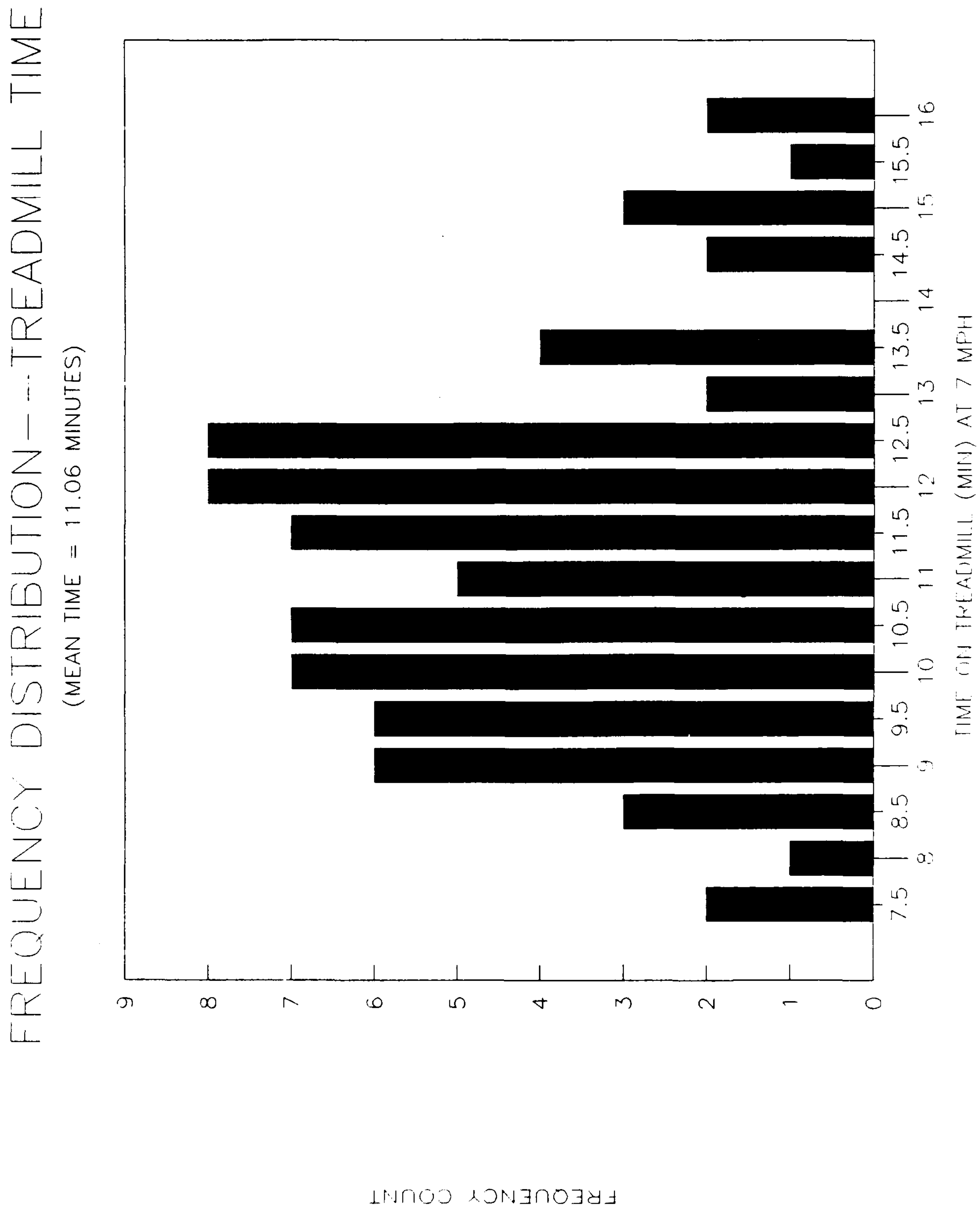
Table 1. Mean values of all subjects treadmill tested in the Human Performance Laboratory in the past six years.

	MEAN ± STANDARD DEVIATION	RANGE
MALES (N = 91)		
Age (yr)	29.33 ± 5.55	19 - 43
Height (cm)	178.89 ± 7.00	165.0 - 193.0
Weight (kg)	76.89 ± 8.46	60.0 - 101.1
Body Fat (%)	12.34 ± 4.68	4.4 - 24.2
$\dot{V}o_{2max}$ ($ml \cdot kg^{-1} \cdot min^{-1}$)	55.18 ± 8.86	31.0 - 75.5
$\dot{V}o_2$ ($L \cdot min^{-1}$)	4.22 ± 0.66	2.0 - 6.3
Max Heart Rate (bpm)	188.31 ± 8.86	168 - 207
FEMALES (N = 28)		
Age (yrs)	29.71 ± 4.97	24 - 38
Height (cm)	166.73 ± 5.67	152.4 - 181.0
Weight (kg)	58.66 ± 6.57	48.0 - 72.8
Body Fat (%)	20.56 ± 4.50	13.5 - 24.7
$\dot{V}o_{2max}$ ($ml \cdot kg^{-1} \cdot min^{-1}$)	45.98 ± 9.66	28.2 - 65.6
$\dot{V}o_2$ ($L \cdot min^{-1}$)	2.70 ± 0.64	1.5 - 3.8
Max Heart Rate (bpm)	189.19 ± 8.18	174 - 205

Table 2. Mean (± standard deviation) values of male and female subjects in two age deciles.

	20 - 29 YEARS (N = 49)	30 - 39 YEARS (N = 37)
MALES (N = 86)		
Age (yr)	25.10 ± 2.23	33.95 ± 2.44
Height (cm)	179.06 ± 7.50	179.08 ± 6.42
Weight (kg)	76.78 ± 8.30	76.89 ± 8.55
Body Fat (%) (N = 53)	10.70 ± 4.26*	14.06 ± 4.44
$\dot{V}o_{2max}$ ($ml \cdot kg^{-1} \cdot min^{-1}$)	56.20 ± 7.94	53.47 ± 10.18
$\dot{V}o_2$ ($L \cdot min^{-1}$)	4.29 ± 0.61	4.09 ± 0.74
Max Heart Rate (bpm)	189.10 ± 8.23	188.43 ± 9.32
	20 - 29 YEARS (N = 15)	30 - 39 YEARS (N = 13)
FEMALES (N = 28)		
Age (yr)	25.67 ± 1.72	34.38 ± 2.81
Height (cm)	167.96 ± 5.79	165.30 ± 5.40
Weight (kg)	58.81 ± 6.96	58.49 ± 6.36
Body Fat (%) (N = 5)	22.20 ± 3.05	18.10 ± 6.51
$\dot{V}o_{2max}$ ($ml \cdot kg^{-1} \cdot min^{-1}$)	46.02 ± 9.13	45.93 ± 10.62
$\dot{V}o_2$ ($L \cdot min^{-1}$)	2.72 ± 0.65	2.69 ± 0.65
Max Heart Rate (bpm)	190.14 ± 6.71	188.15 ± 9.69

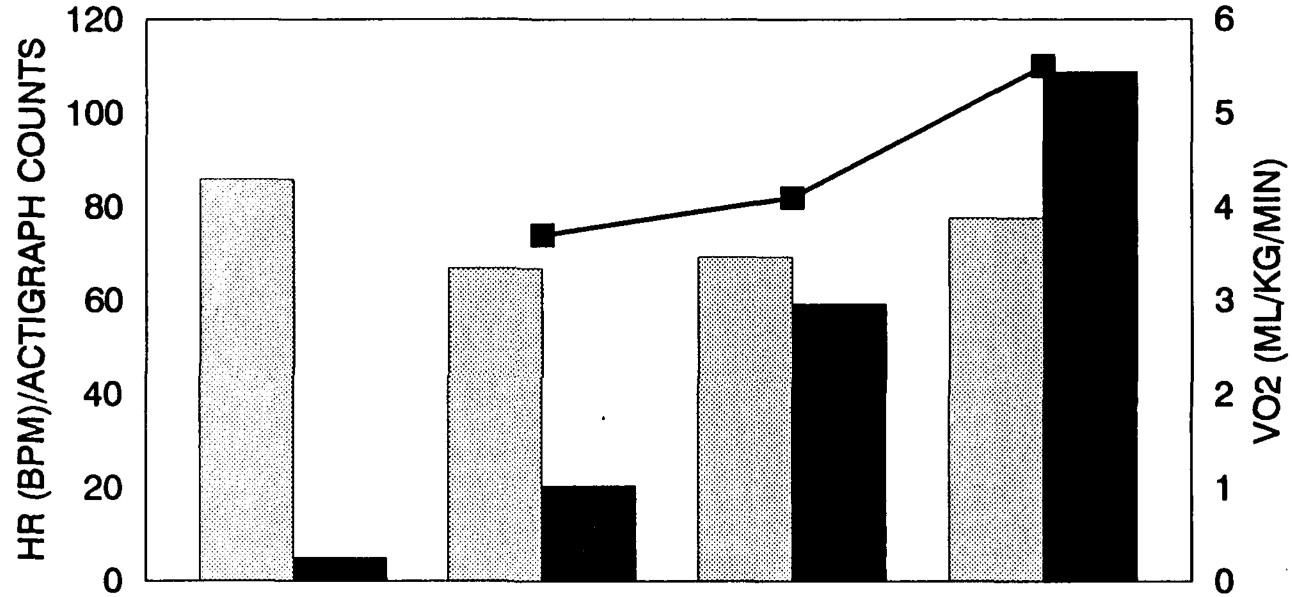
Figure 1



FREQUENCY DISTRIBUTION — — TREADMILL TIME
(MEAN TIME = 11.06 MINUTES)
0 1 2 3 4 5 6 7 8 9
7.5 8 8.5 9 9.5 10 10.5 11 11.5 12 12.5 13 13.5 14 14.5 15 15.5 16
TIME ON TREADMILL (MIN) AT 7 MPH
FREQUENCY COUNT

Figure 2

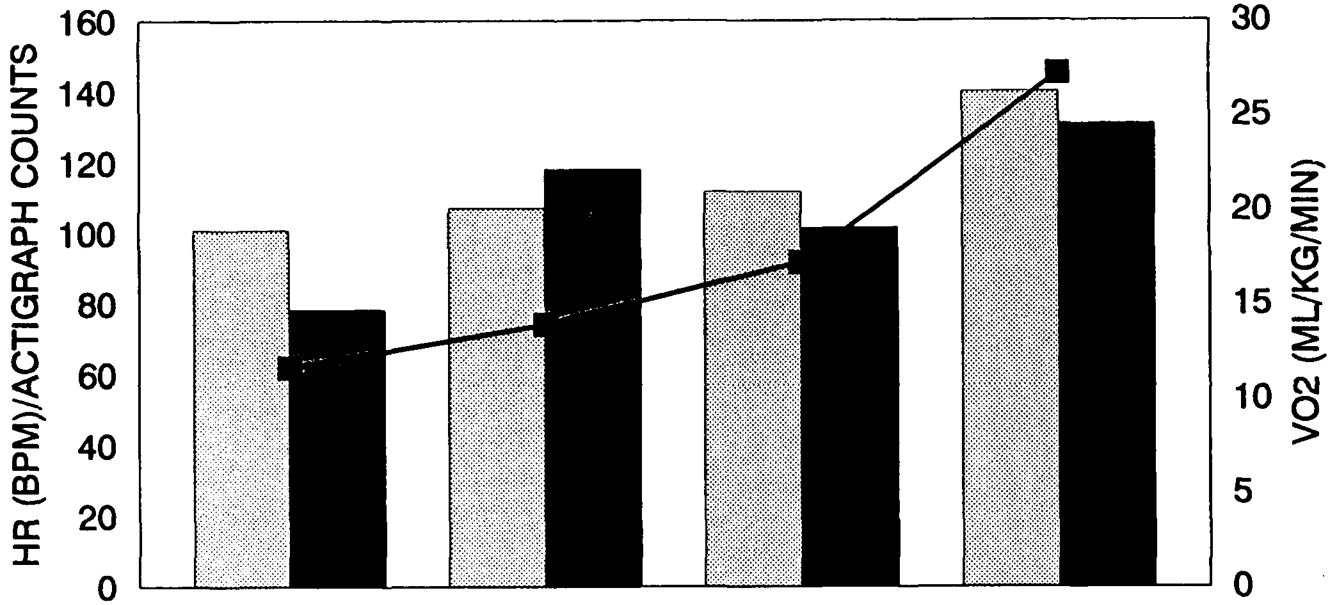
MEAN VALUES OF HEART RATE, ACTIGRAPH COUNTS AND OXYGEN CONSUMPTION DURING DAILY ACTIVITIES



DAILY ACTIVITY TASK	MATH	READ	TYPE	GAME
VO2 Uptake		3.7	4.1	5.5
Heart Rate	85.9	66.9	69.3	77.6
Actigraph	5.0	20.4	59.3	108.7

Figure 3

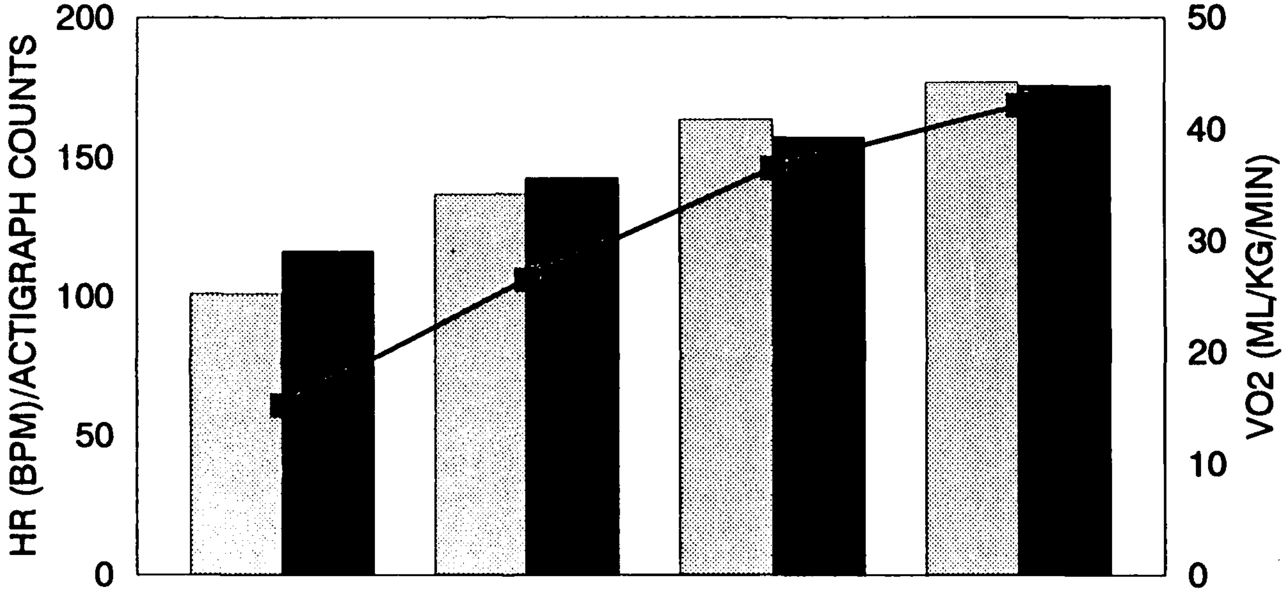
MEAN VALUES OF HEART RATE, ACTIGRAPH COUNTS AND OXYGEN CONSUMPTION DURING EXERCISE ACTIVITIES



EXERCISE TASKS	BEND 28 BPM	BEND 48 BPM	STEP 20 SPM	STEP 36 SPM
VO2 UPTAKE ——	11.6	13.9	17.2	27.2
HEART RATE	100.8	107.0	111.6	139.7
ACTIGRAPH	78.3	117.9	101.3	130.7

Figure 4

MEAN VALUES OF HEART RATE, ACTIGRAPH COUNTS AND OXYGEN CONSUMPTION DURING EXERCISE



TREADMILL SPEED (MPH)	3.0	4.6	6.2	7.5
VO2 UPTAKE ———	15.2	26.5	36.5	42.1
HEART RATE	101.0	136.6	163.5	176.7
ACTIGRAPH	116.3	142.4	157.2	175.6

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LIST OF PERSONNEL SUPPORTED IN WHOLE OR IN PART BY PROJECT 90MM0531

1. Leslie C. Montgomery (Associate Investigator)
2. Audrey Menkes
3. Kathleen Gallagher
4. Ulrike Trostmann
5. Bridget Kealey